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MISSION G ELECTRICAL POWER SUBSYSTEM AND ENVIRONMENTAL CONTROL SUBSYSTEM CONSUMABLES ANALYSIS AS DEFINED FOR CONFIGURATION CONTROL

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PROJECT APOLLO

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SUMMARY

The analyses presented in this report indicate that adequate margins exist in the electrical power subsystem (EPS) and environmental control subsystem (ECS) consumables for Mission G for both the command and service modules (CSM) and the lunar module (LM). Of the available oxygen (O_2) for the CSM, 21 percent remains at mission completion; of the available hydrogen (H_2), 24 percent remains. Both the potable and waste water tanks were full at command module (CM) and service module (SM) separation.

The LM descent stage electrical energy remaining at lunar lift-off for the nominal powered-down configuration is 30 percent of the available. For the same power configuration 41 percent of the descent stage water remains at lunar lift-off. The descent stage oxygen margin is 27 percent of the available. The ascent stage margin at the completion of crew transfer is 47 percent of the available, the oxygen margin is 63 percent of the available, and the water margin is 62 percent of the available. In all cases, the tanks were assumed to have been loaded to full capacity.

INTRODUCTION

Detailed EPS and ECS consumables analyses were performed for Mission G (CSM-107/LM-6). The data used in the analyses were assumed to be accurate to within ±10 percent. The consumables estimates provided by this study were based on preliminary knowledge of crew procedures. The procedures used for this study are not intended to define mission rules or crew procedures, but are used in an attempt to establish consumables requirements. The mission timeline used for these analyses is given in table I.

The analyses were performed by the Consumables Analysis Section (CAS) of Mission Planning and Analysis Division (MPAD) with support from TRW Systems Group on the ECS analysis. Information was also obtained from

North American Rockwell, Grumman Aircraft and Engineering Corporation, Flight Crew Support Division, Flight Control Division, Apollo Spacecraft Program Office, and Instrumentation and Electronics Systems Division in arriving at the final results.

SYMBOLS

AGS	abort guidance subsystem
ATCA	attitude and translation control assembly
CDH	constant differential height
CO_2	carbon dioxide
CSI	concentric sequence initiation
EVA	extravehicular activity
FDAI	flight director attitude indicator
G&N	guidance and navigation system
GASTA	gimbal angle sequencing transformation assembly
g.e.t.	ground elapsed time
GSE	ground support equipment
H_2O	water
IMU	inertial measurement unit
IVT	intravehicular transfer
LGC	LM guidance computer
LIOH	lithium hydroxide
PLSS	portable life support system
PNGS	primary navigation and guidance subsystem

CSM ELECTRICAL POWER SUBSYSTEM ANALYSIS AND RESULTS

The EPS assumptions and data used for this analysis are as follows:

1. Three fuel cells and two inverters were in operation during all mission activities except boost, ΔV thrusting, and entry activities.

2. Three fuel cells, two inverters, and two batteries were in operation during boost, ΔV thrusting, and entry activities.

3. The mission timeline was the same as that defined in references 1, 2, and 3.

4. The EPS component power requirements were the same as those in references 4 and 5.

5. Each fuel cell was purged once every 24 hours.

6. EPS hydrogen consumption rate (lb/hr) = 0.00257 × fuel cell current.

7. EPS oxygen consumption rate (lb/hr) = 7.936 × hydrogen consumption rate.

8. No H_2 or O_2 venting was assumed.

For this analysis, CSM O_2 and H_2 tanks were assumed loaded to capacity. The quantities available for performance of the lunar landing mission are shown in table II. The switch to internal reactants is made at T - 30 hours for oxygen and T - 25 hours for hydrogen as shown in table III. The electrical requirements vary from 18 to 100 amp during the 34-hour prelaunch period which includes a 4-hour launch window. Due to prelaunch O_2 and H_2 requirements, the oxygen available at lift-off is 593.4 lb and the hydrogen available is 51.2 lb. The total H_2 remaining at CM-SM separation is 13.4 lb, which results from a total H_2 requirement (prelaunch and flight) of 42.0 lb. The O_2 required for electrical power is 299.9 lb. The H_2 and O_2 profiles are shown in figure 1. The O_2 profile includes both EPS and ECS requirements.

The constraint on transearth coast time as a function of O_2 remaining is shown in figure 2 for a nominal mission with and without a 10 percent planning margin. The time constraint following an oxygen tank failure at transearth injection is also shown. For the oxygen tank failure at TEI a powered-down configuration of 40 amp was assumed for the transearth return.

For both nominal and contingency cases, the average load in lunar orbit was 74.1 amp. Using the above assumptions the time in lunar orbit was plotted as a function of transearth return time. The slopes for the nominal and tank-failure cases differ because of the different power configurations assumed during transearth flight.

CSM ENVIRONMENTAL CONTROL SUBSYSTEM ANALYSIS AND RESULTS

The ECS assumptions and data used for this analysis are as follows:

1. Urine H_2O loss was 0.11 lb/hr per man.

2. Food H_2O was 0.125 lb/hr.

3. Average metabolic rate was 467 Btu/hr per man.

4. Desired cabin temperature of 75°F was assumed.

5. Radiator absorptivities of 0.2 and 0.356 were assumed.

6. Initial H_2O quantities at lift-off were 25-lb potable and 10-lb waste.

7. Evaporator effectiveness was 95 percent. (The effectiveness is the ability of the evaporator to evaporate the water dumped into the system without losing any water through droplets carried off by the steam.)

8. Cabin O_2 leakage rate was 0.2 lb/hr.

9. Waste management O_2 leakage rate was 0.017 lb/hr per man.

10. Metabolic O_2 usage rate was 0.077 lb/hr per man.

11. The O_2 purge rate of the water tank was 0.056 lb/hr which is the maximum flow based on the orifice size.

12. From lift-off a total of 7 lb O_2 was used to purge the cabin atmosphere through the waste management system. The total time required was 8 hours.

13. The tunnel was pressurized at transposition and docking. Three full pressurizations of the LM were assumed.

The ECS oxygen required for the mission was 158.9 lb. This value is based on crew metabolic requirements, CSM and LM pressurizations, water tank purge, waste management, and cabin leakage.

The potable and waste water tanks are full from 51 hours after launch until the end of mission. A degraded radiator with absorptivity $\alpha = 0.356$ has no significant impact on the mission since water production remains greater than water boiled throughout the mission. The water tank status as a function of time is displayed in figure 3. The total water boiled for an undegraded radiator is 40 lb as shown in figure 4. For $\alpha = 0.356$, the water boiled is approximately 57 lb. From figure 4 the highest usage rate occurs during the lunar orbit; however, the boil rate is less than 1 lb per hour for the degraded radiator. Secondary coolant loop operation was not considered for this analysis.

LM ELECTRICAL POWER SUBSYSTEM ANALYSIS AND RESULTS

The descent stage electrical load analysis for Mission G was performed utilizing the flight plans in references 2 and 3. Reference 6 contains the power levels of the various equipment presented in the analysis. The LM EPS and ECS consumables loadings are displayed in table IV. The LM prelaunch procedures are shown in table V.

Three distinct descent stage electrical equipment configurations were considered in this study. This report does not attempt to weigh the merits or disadvantages of each but instead is confined to an objective appraisal of the electrical energy required to support each configuration.

For case 1, which is the nominal case, the LM is powered down (as suggested in ref. 6) during the long periods of inactivity on the lunar surface. The power profile depicted in figure 5 results from the equipment utilization associated with case 1.

Case 2 differs from the nominal case in that the LM is partially powered up; the IMU, LGC, and AGS have been changed from the standby to the operational mode. This particular mode eliminates the 25- to 30-minute warmup constraint imposed on the G&N equipment. The effect of the additional 376-watt drain on the descent stage batteries is presented in figure 5.

A fully powered-up LM is used in case 3, for which the equipment in case 2 and the ATCA, GASTA, and FDAI are considered to be on for the entire lunar stay. The resulting electrical energy profile is also presented in figure 5.

The ascent stage electrical load analysis was performed on a nominal 3.5-hour interval between lift-off and spacecraft docking as defined in reference 2. Only one electrical power configuration was considered for the LM ascent phase of the mission. The ascent stage electrical requirements are shown in figure 6. The LM ascent consumables are adequate for the nominal 3.5-hour rendezvous; however, contingency rendezvous schemes as currently planned are limited by the total electrical power and oxygen on the ascent stage.

Significant assumptions used in the formulation of this analysis are as follows:

1. Ascent stage batteries were connected in parallel with the descent stage batteries during powered descent to the lunar surface and initial postlanding evaluation. This assumption is documented in references 2 and 6.

2. As presented in reference 2, the current flight plan demands two lunar surface EVA's and a 25.5-hour lunar surface stay time.

3. In the nominal power configuration (case 1), the PNGS was left in standby, and the AGS was turned off for long periods on the lunar surface. This was done to conserve electrical power and increase reliability of the equipment.

4. The LM was left completely powered up for the first 2 hours subsequent to landing in order to simulate a lift-off on the first CSM pass over the landing site. This assumption is also documented in reference 2.

5. The S-band power amplifier and television camera were assumed on at all times during both EVA's.

6. There was one inflight IMU alignment from lunar lift-off through docking. As found in reference 2, this alignment was assumed to occur between the CSI and CDH maneuvers.

Total battery requirements for all three descent stage equipment utilizations plus the ascent stage electrical energy demand are given in table VI. It can be seen that if the LM is fully powered up during the lunar stay (case 3), it may be necessary to use ascent stage batteries if the nominal lunar launch opportunity is missed.

LM ENVIRONMENTAL CONTROL SUBSYSTEM ANALYSIS AND RESULTS

The water balance analysis was based on the following considerations as specified in reference 6:

1. The structural heat load required 1 lb/hr of H_2O.

2. H_2O consumed due to LIOH-CO_2 reaction heat was 2.4×10^{-4} lb/Btu (metabolic rate).

3. H_2O produced by LIOH-CO_2 reaction was 7.72×10^{-5} lb/Btu (metabolic rate).

4. H_2O consumed due to crew metabolic heat was 1/1040 lb/Btu (metabolic rate).

5. H_2O consumed due to urine dump was 0.11 lb/hr per man.

6. H_2O required per PLSS refill was 9.15 lb.

The ascent stage water required to successfully complete the powered ascent and rendezvous phase of Mission G is 30.0 lb. The descent stage H_2O demands for electrical equipment configurations 1, 2, and 3 are 181.8, 202.3, and 210.3 lb, respectively. Figure 7 depicts the ascent stage H_2O usage, and figure 8 reveals descent stage water consumption for cases 1, 2, and 3, respectively.

The O_2 consumption was calculated based on the following assumptions:

1. There was a cabin leak of 0.2 lb/hr.

2. Metabolic O_2 consumed was 1.643×10^{-4} lb/Btu (metabolic rate).

3. There was a high pressure leak of 0.005 lb/hr in both the ascent and descent stage O_2 supplies.

4. O_2 consumption due to a PLSS refill was 0.92 lb; each PLSS was refilled once.

5. Each of the three LM repressurizations on the lunar surface required 6.62 lb of O_2.

The descent stage O_2 usage is presented in figure 9 and results in the supply having been depleted to the 18.3-lb level at lunar surface lift-off. Figure 7 presents the ascent stage O_2 profile. The O_2 remaining in the ascent stage at the nominal time of crew transfer is 2.7 lb.

The LM water and oxygen requirements, plus the loaded and residual quantities, are summarized in table VII. Descent stage water usage is presented for all three electrical equipment configurations or cases.

CONCLUSIONS

For the nominal lunar mission considered in this report satisfactory EPS and ECS consumables margins are found to exist for both the CSM and LM.

TABLE I.- MISSION TIMELINE

Mission time	Mission phase
T - 30 hours to launch	Prelaunch[a]
Launch to 4.5 hours	Earth ascent and parking orbit
4.5 to 79.5 hours	Translunar coast
79.5 to 138 hours	Lunar orbit[b]
138 to 244.75 hours	Transearth coast
245 hours	Splashdown

TABLE II.- CSM CONSUMABLES

Consumable	Loaded	Available[c]
O_2, lb	640.0	627.0
H_2, lb	56.0	55.4
Potable H_2O, lb	0.0	25.0[d]
Waste H_2O, lb	10.0	10.0
Battery, amp-hr	120.0	120.0

[a]Includes maximum launch window of 4.0 hours.

[b]Includes sleep period after rendezvous and docking.

[c]Available at time of loading.

[d]Available at lift-off from prelaunch production.

TABLE III.- CSM PRELAUNCH PROCEDURES

Mission time	Event
T - 5 days	Complete loading potable and waste H_2O
T - 30 hours	Complete loading O_2 and switch to internal O_2 for fuel cell requirements
T - 25 hours	Complete loading H_2 and switch to internal H_2 for fuel cell requirements
T + 4 hours	Lift-off after maximum launch window

TABLE IV.- LM CONSUMABLES

Consumable	Loaded	Available
(a) Descent stage		
O_2, lb	48.0	44.1
H_2O, lb	320.0	310.2
Battery, amp-hr	1600.0	1600.0
(b) Ascent stage		
O_2, lb	4.8	4.3
H_2O, lb	82.0	79.5
Battery, amp-hr	592.0	592.0

TABLE V.- LM PRELAUNCH PROCEDURES

Mission time	Event
T - 18 days	Ascent and descent H_2O loading completed.
T - 63 hours	Complete ascent and descent O_2 loading.
T - 22 hours	Complete supercritical helium loading.
T - 30 min	Switch from GSE to LM battery power

TABLE VI.- LM DESCENT AND ASCENT STAGE EPS REQUIREMENTS

(a) Descent stage

	Electrical energy, KW-hr
Battery capacity	46.9
Required:	
Case 1	32.8
Case 2	40.4
Case 3	43.3
Margin at lunar lift-off:	
Case 1	14.1
Case 2	6.5
Case 3	3.6

(b) Ascent stage

	Electrical energy, KW-hr
Battery capacity	17.8
Required	9.4
Margin at end of crew transfer	8.4

TABLE VII.- LM WATER AND OXYGEN REQUIREMENTS

(a) Descent stage

	O_2, lb	H_2O, lb
Loaded	48.0	320.0
Unusable	3.9	9.8
Available for mission	44.1	310.2
Required:		
Case 1	25.8	181.8
Case 2	25.8	202.3
Case 3	25.8	210.3
Available at lunar lift-off:		
Case 1	11.7	128.3
Case 2	11.7	107.9
Case 3	11.7	99.9

(b) Ascent stage

	O_2, lb	H_2O, lb
Loaded (full tanks)	4.8	82.0
Unusable	0.5	2.5
Available for mission	4.3	79.5
Required for mission	1.6	30.0
Available at completion of crew transfer	2.7	49.5

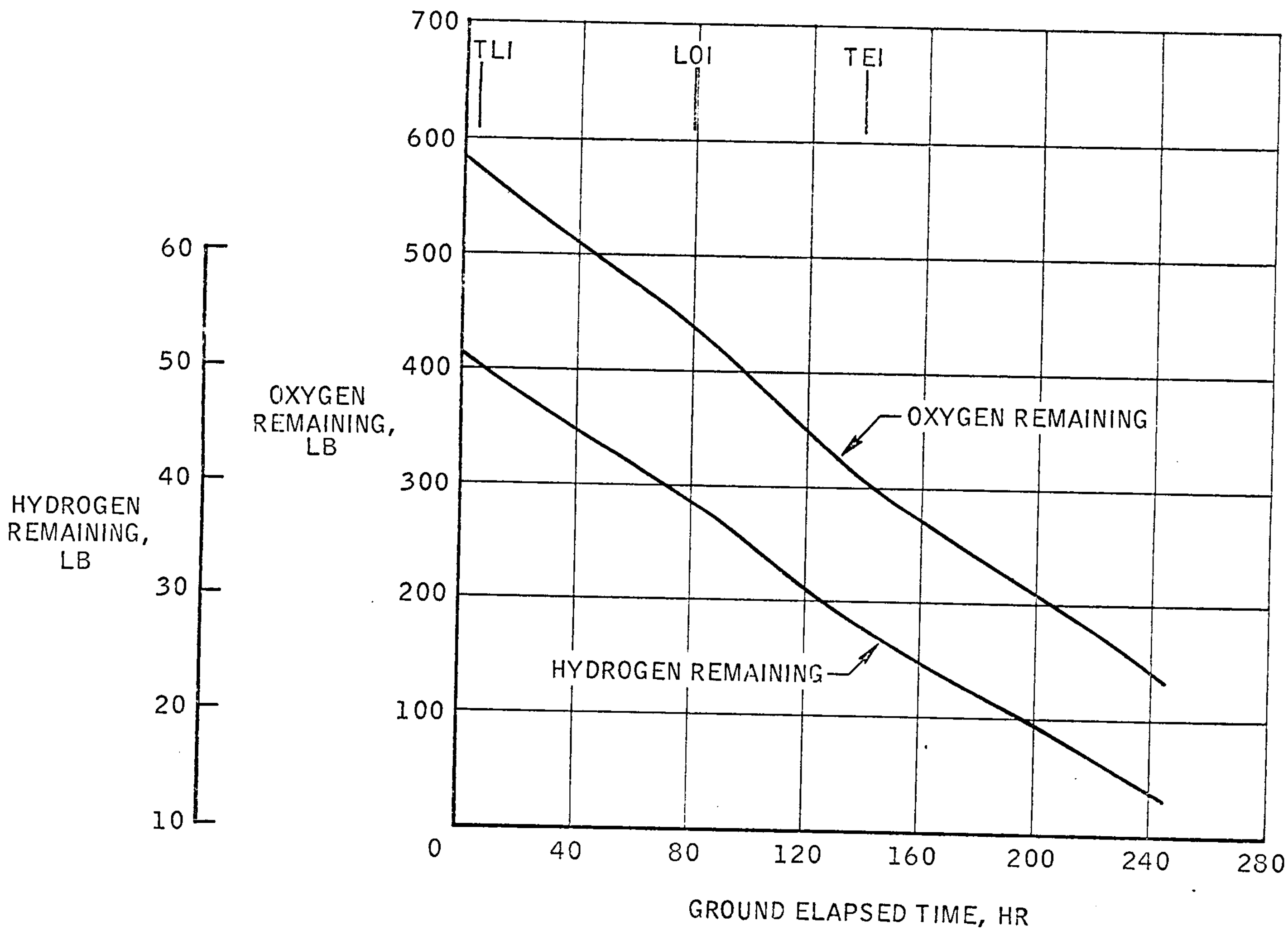

Figure 1.- CSM cryogenics remaining as a function of mission time.

Ref. MPAD 3446 S(IU)

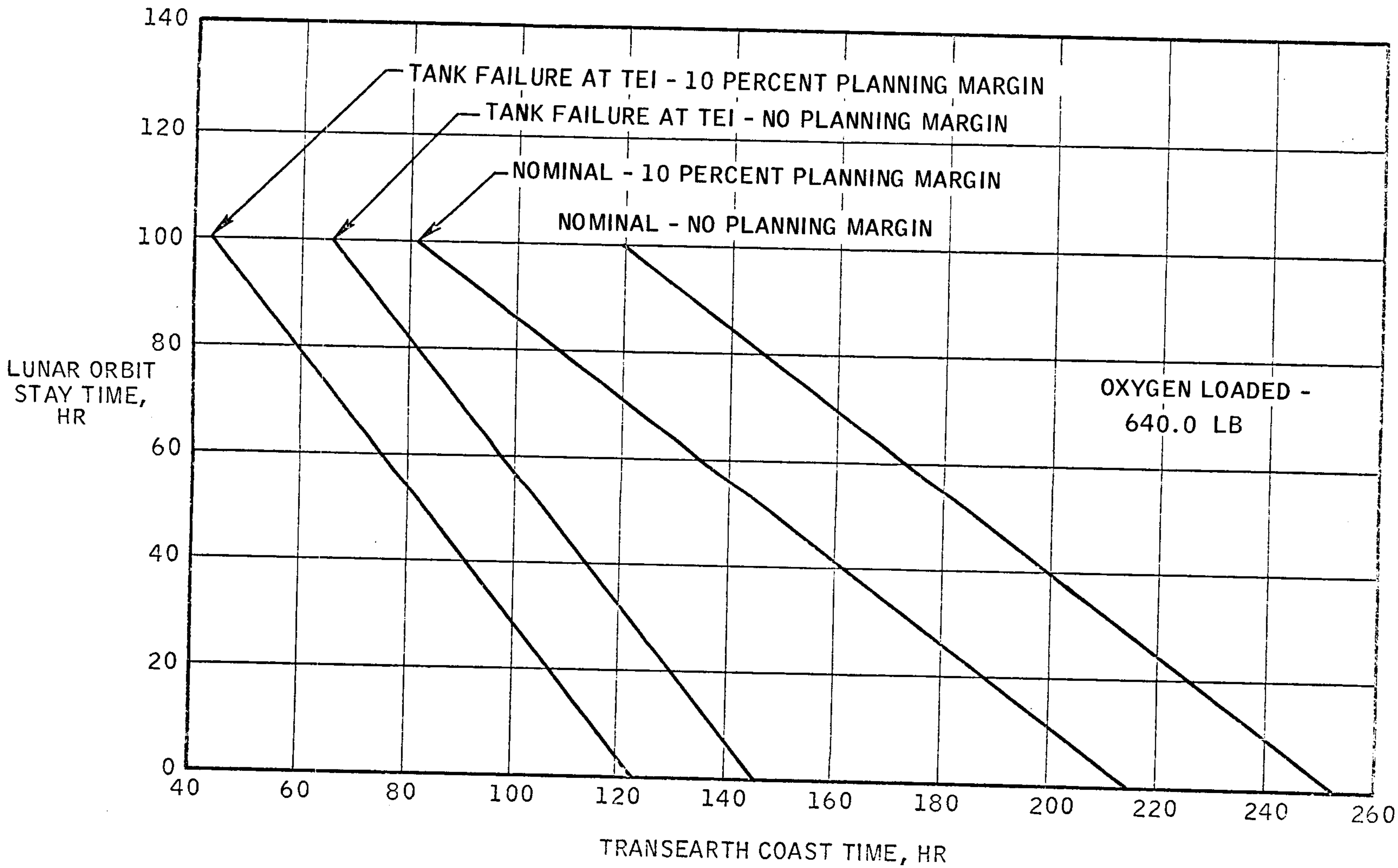

Figure 2.- Transearth flight time as a function of oxygen remaining after lunar orbit stay.

Ref. MPAD 3366 S(IU)

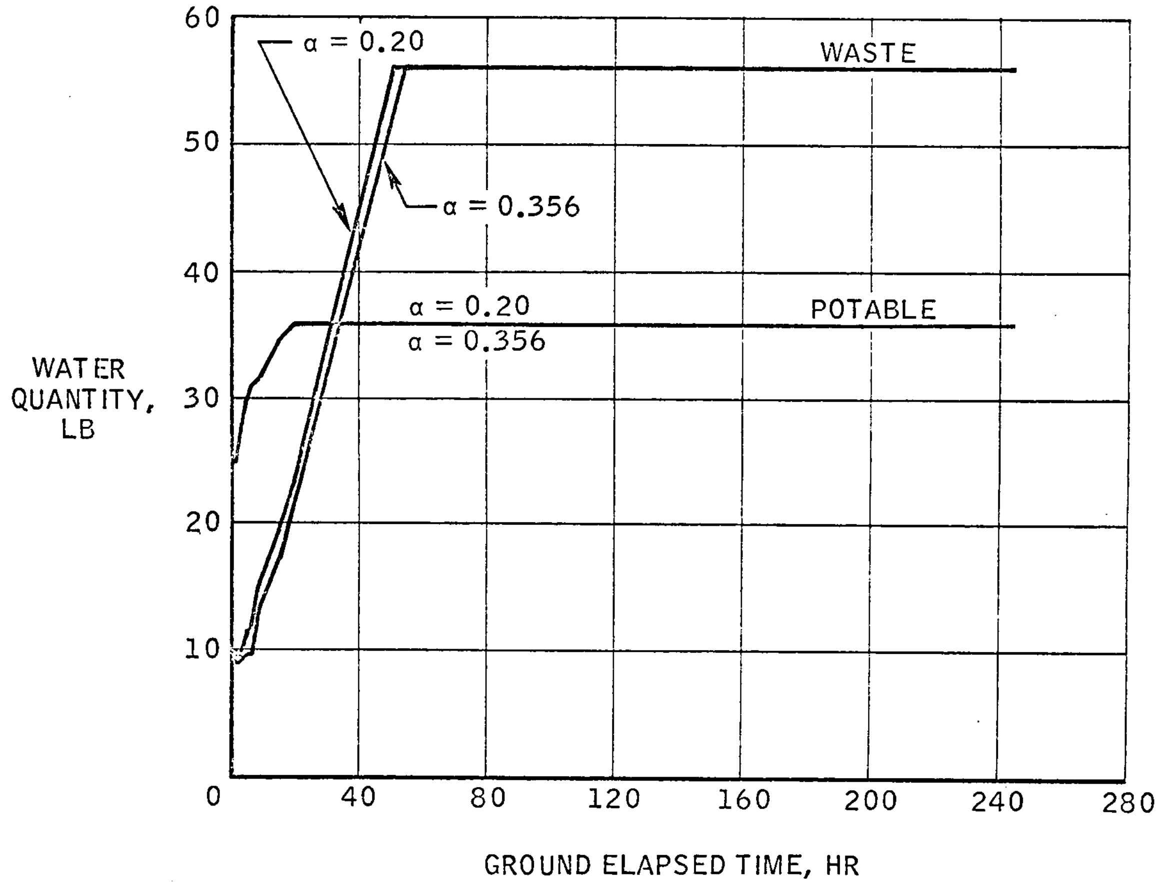

Figure 3.- Water available for lunar landing.

Ref. MPAD 3442 S(IU)

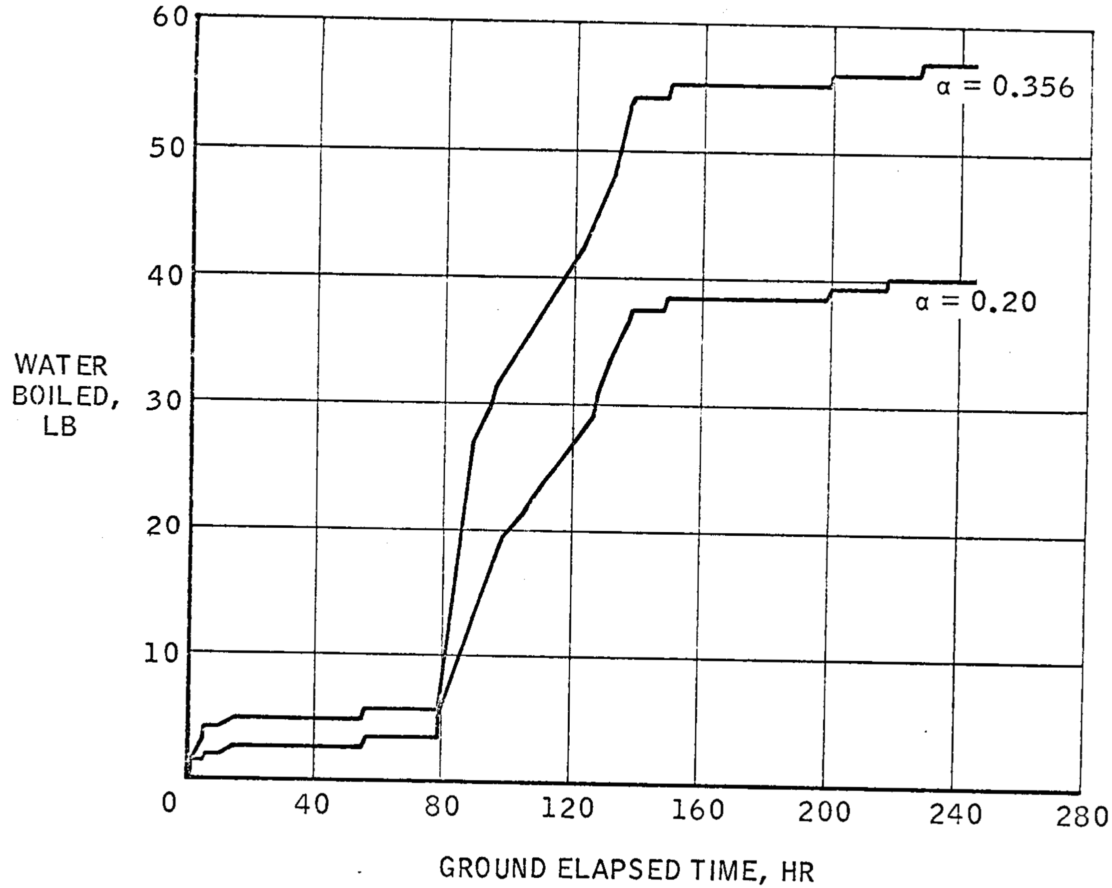

Figure 4.- Water boiled as a function of mission time.

Ref. MPAD 3443 S(IU)

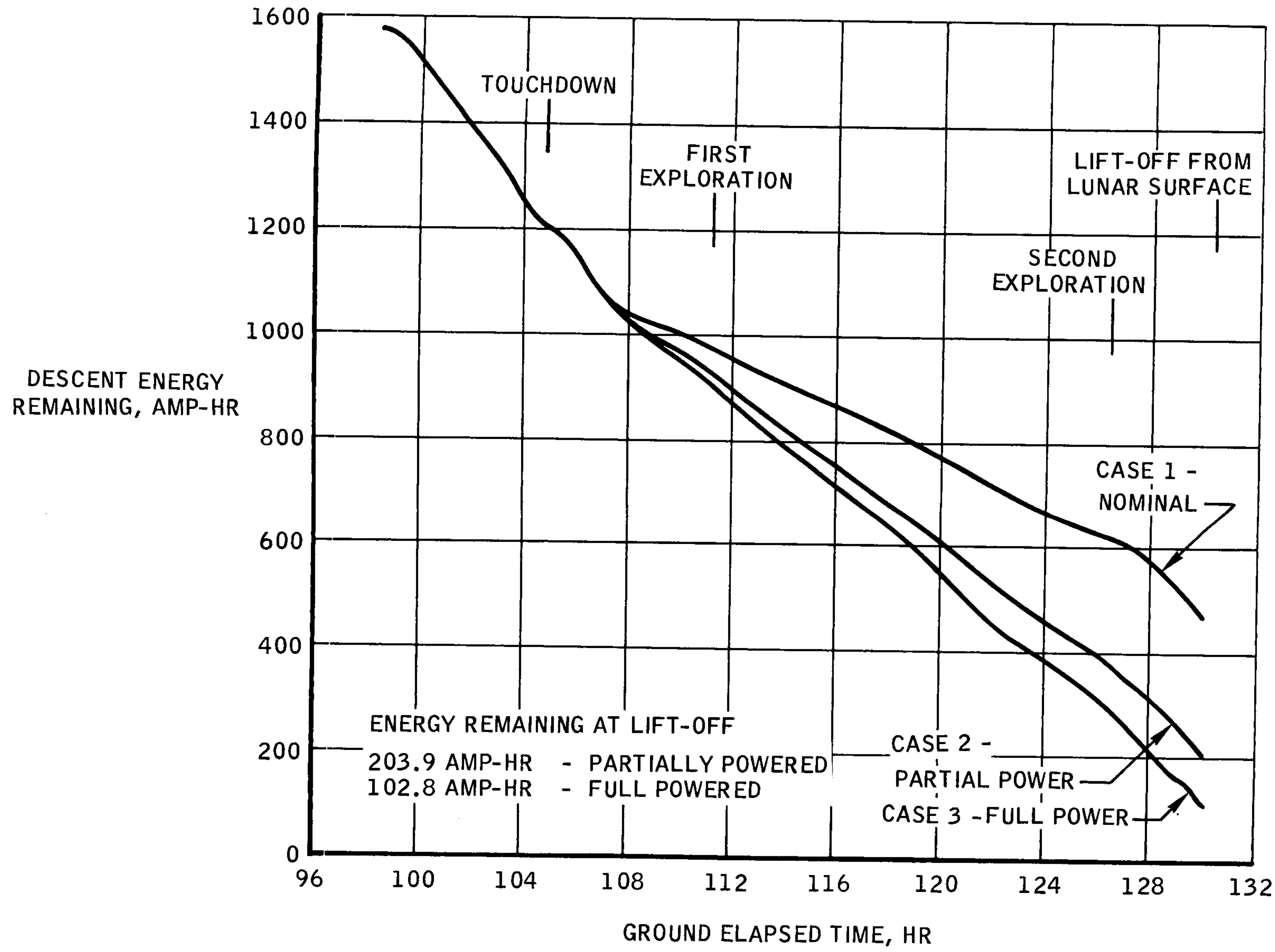

Figure 5.- Descent battery energy profile from lunar orbital checkout to lift-off from lunar surface.

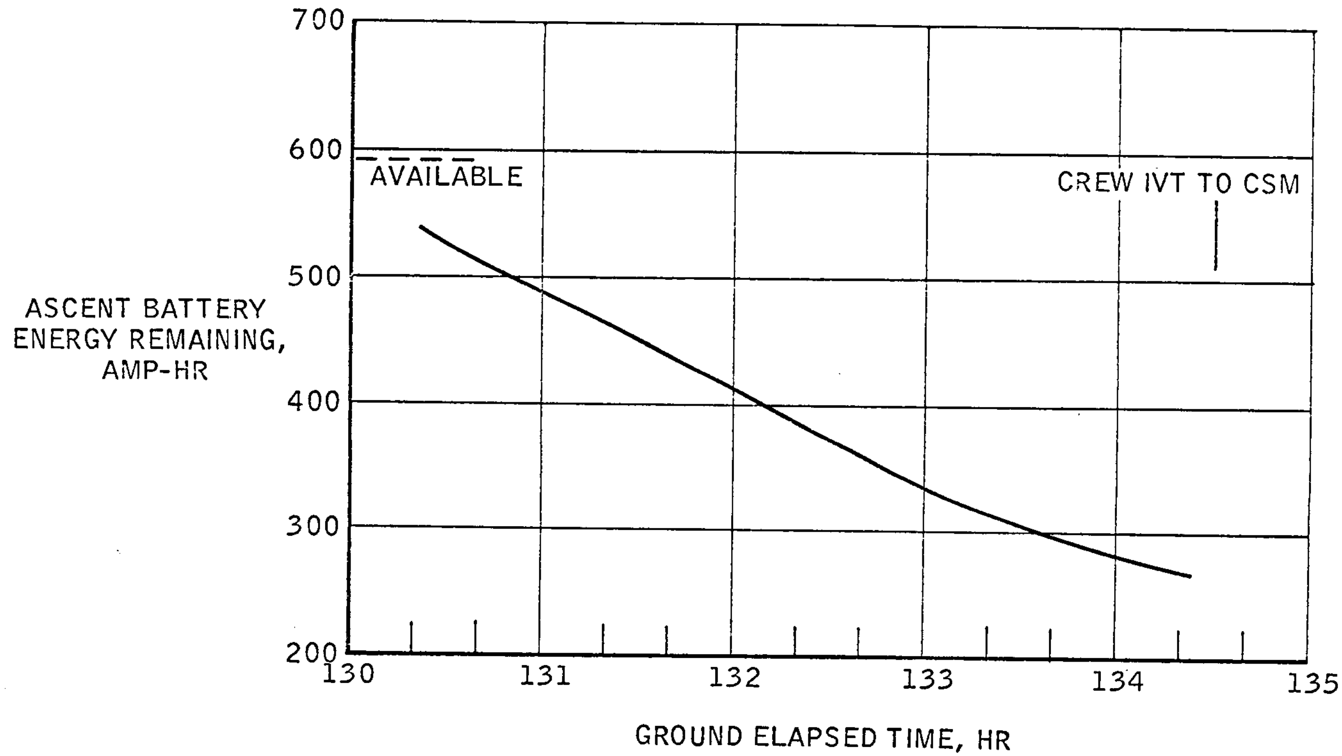

Figure 6.- Ascent battery energy profile from lift-off from lunar surface to IVT to CSM.

Ref. MPAD 3439 S(IU)

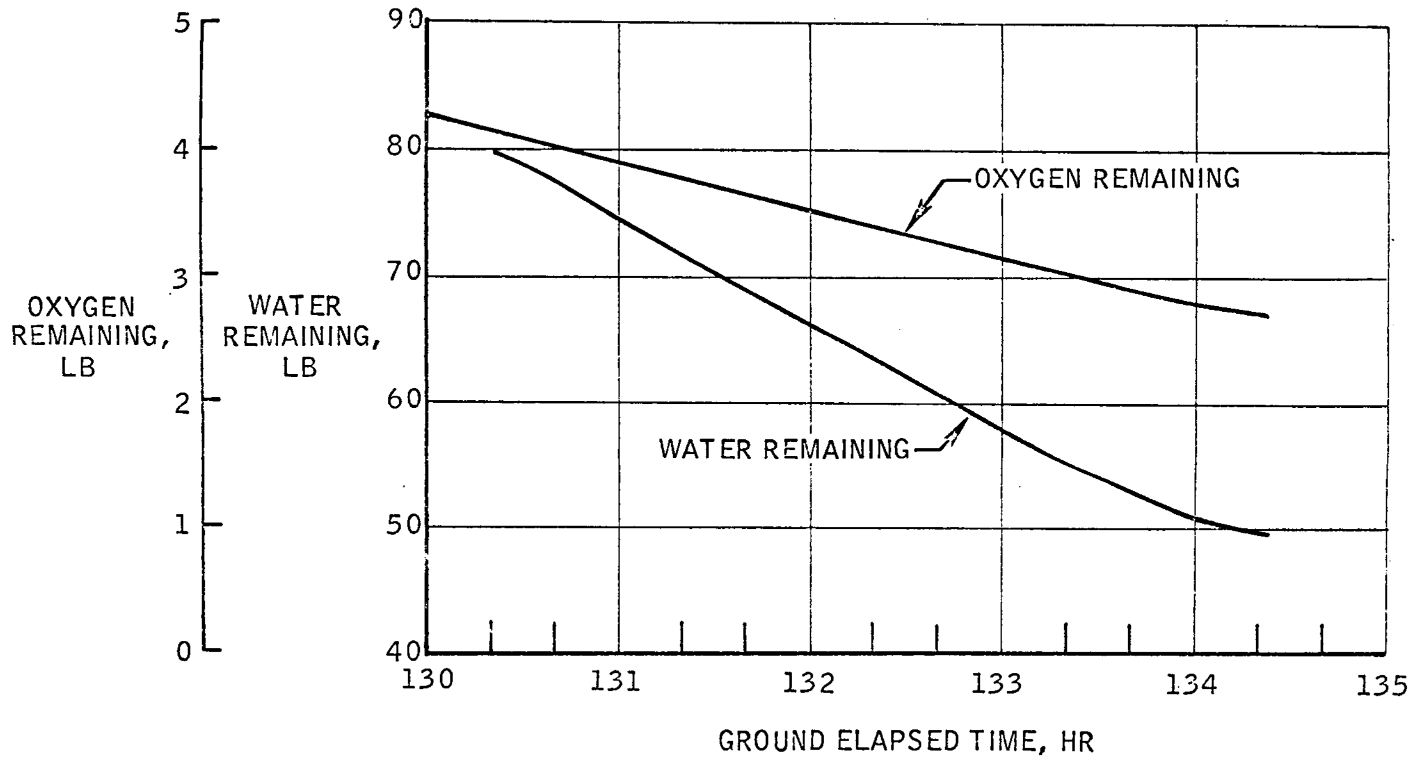

Figure 7.- Ascent stage water and oxygen profile from lunar lift-off to IVT to CSM.

Ref. MPAD 3435 S(IU)

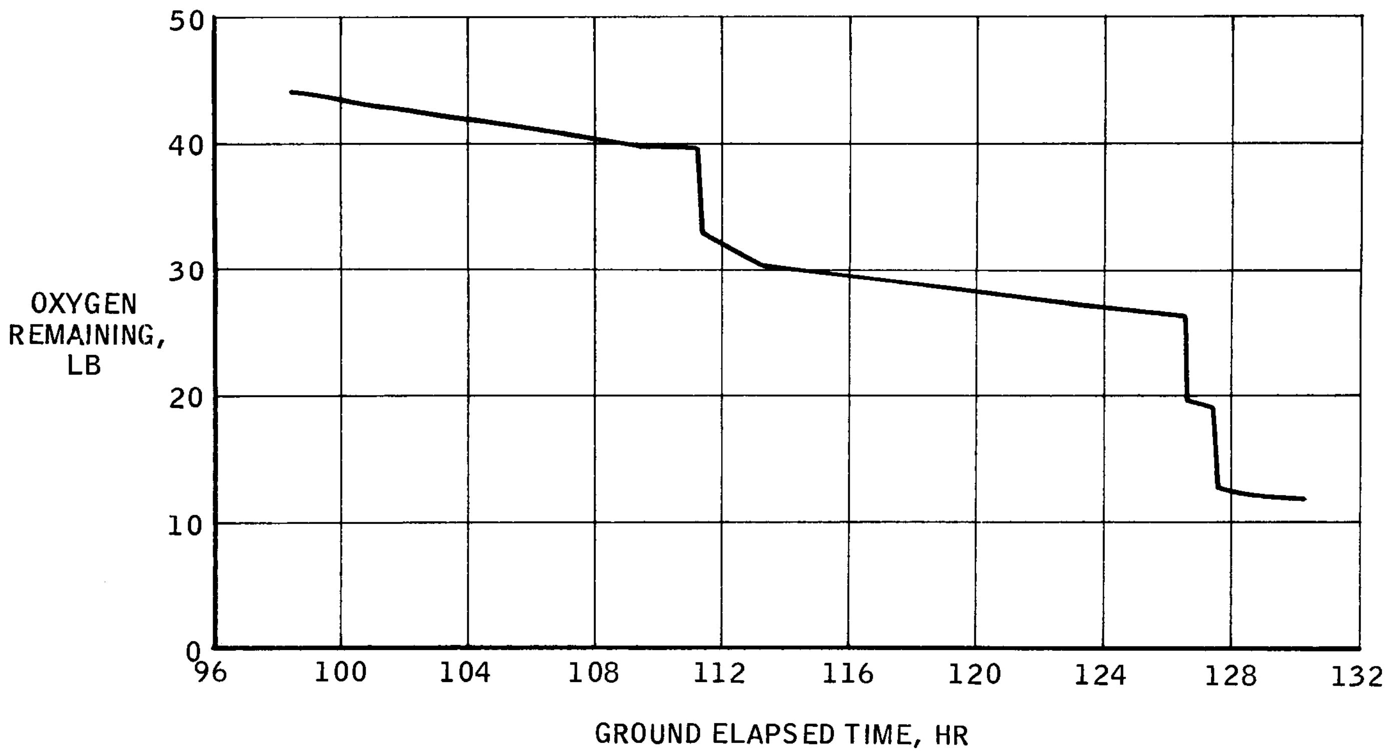

Figure 8.- Descent stage oxygen profile from lunar orbit checkout to lunar lift-off.

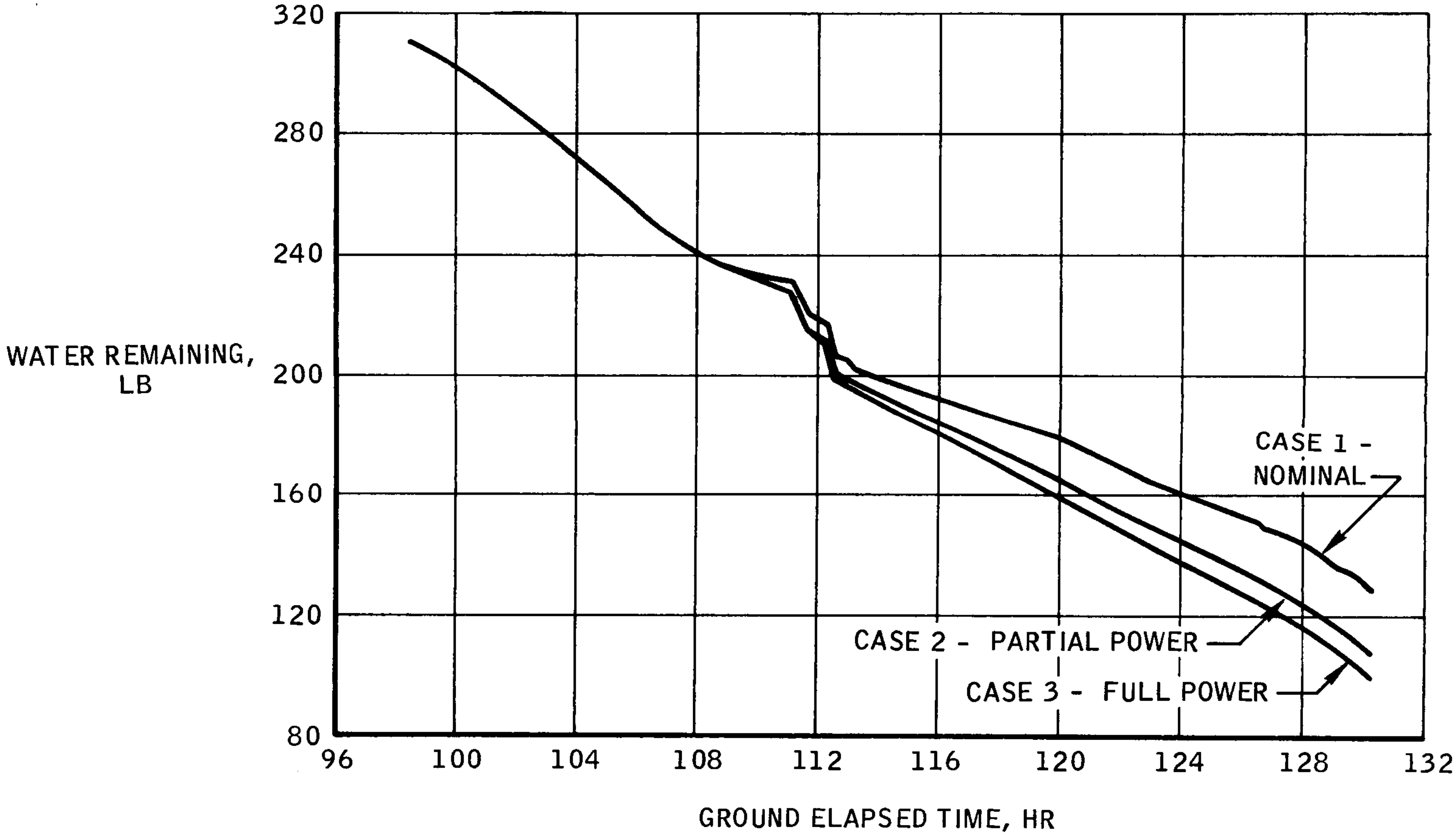

Figure 9.- Descent stage water profile from lunar orbit checkout to lunar lift-off.

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